NanoSemi's Value Proposition and Competitive Advantages

About NanoSemi

NanoSemi develops intellectual property (IP) to improve signal quality of communication systems. We apply our expertise in mathematics, digital signal processing, and RF to the problem of linearizing and improving the performance of RF, analog, and data converter circuits. Today our technology enables higher throughput connections for 5G, Wi-Fi, and WiGig smartphones and base stations while simultaneously reducing energy consumption. The result is higher quality data streams and connections for consumers while improving smartphone battery life.

In this paper, we explain how Nanosemi is different from other approaches, but first, here are three tables showing the resulting benefits to the user. An explanation of benefits follows in subsequent sections.

Table 1 shows a comparison of a use case for 5G mobile devices operating at frequency band < 6GHz. 5G mobile devices implemented with NanoSemi's IP in SoC can have the RF transmit power twice as devices without NanoSemi's IP (for the same power amplifier in 5G SoC). Similarly, power efficiency of the device can be twice as large and the bandwidth of full 400MHz can be utilized instead of one NR (i.e., 100MHz).

Performance	w/o NanoSemi	w/ NanoSemi
Output Power	24 dBm	27 dBm
Power Efficiency	15%	>30%
Bandwidth	100MHz	400MHz

Table 1

Table 2 shows a comparison of a use case for 5G mm-wave or WiGig devices operating at mm-wave frequency bands. mm-wave devices implemented with NanoSemi's IP in SoC can have the mm-wave transmit power twice as the device without NanoSemi's IP. Or, said differently, the required array size for the mm-wave device with NanoSemi's IP can be half. Power efficiency can be 3x higher, and full 800MHz can be utilized for 5G and 2GHz for 802.11ad.

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Performance	w/o NanoSemi	w/ NanoSemi
Array Size required to deliver same transmit output power	8x4	4x4
Power Efficiency	<5%	>15%
Bandwidth with 256 QAM modulation	200MHz	800MHz

Table 2

Because the device can output twice the transmit power with the same array size, the array size can be reduced by half. If we only focus on the area of power amplifiers, the silicon area occupied by power amplifiers is reduced by half, using NanoSemi's IP. It results in cost savings of 50% just from the array size reduction. This calculation assumes that the process node of this PA is 28nm, the wafer size is 300mm (in diameter), the wafer cost ~$3000 and the die yield of 84% for 35mm² die area.

Estimate	NanoSemi	Others
Output Power of Power Amplifier per Element	**10 dBm (10 mW)**	**7 dBm (5 mW)**
Array Size to achieve 22dBm (~160mW)	**4x4**	**8x4**
Occupied Area by Power Amplifiers	**35 mm²**	**70 mm²**
Cost per Array	**$ 2.44** (assumes 84% yield)	**$ 4.88** (assumes two 4x4 arrays)

Table 3

About NanoSemi' IP Porfolio

NanoSemi's Signal Correction Portfolio (**NSCP**) integrates into the digital baseband of a System on Chip (SoC) modem to digitally correct for nonlinearities, linear imperfections, interference and load variations produced either on the transmit or receive parts of the RF signal chain such as the Power Amplifier (PA), transceivers, data converters and filters. Figure 1a and 1b show both nonlinear and linear correction IP cores for transmitter and receiver, respectively. Linearizer™, highlighted in red is redrawn in Figure 2 (without CFR).

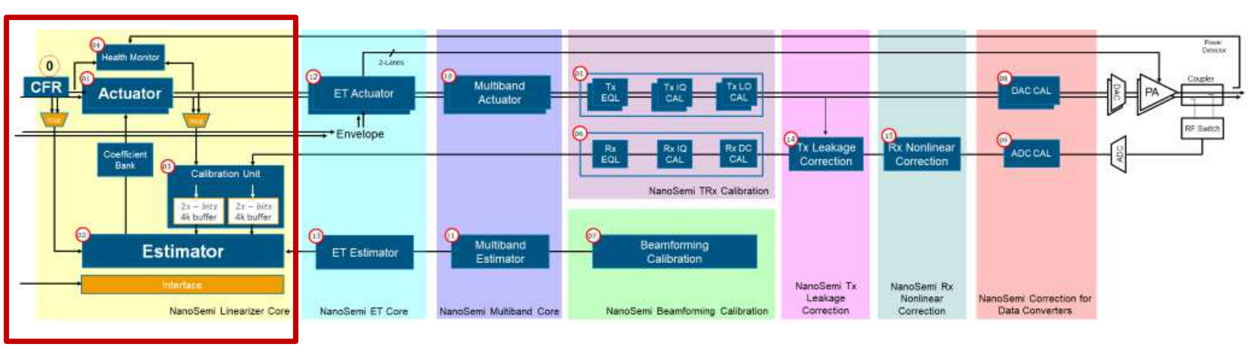

Figure 1a: Signal correction IP cores for transmitter

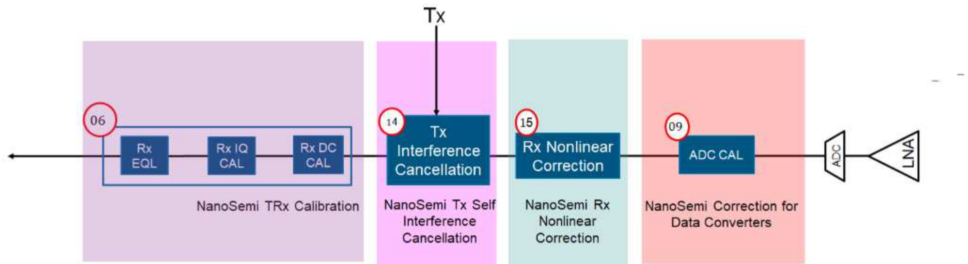

Figure 1b: Signal correction IP cores for receiver

NanoSemi Linearizer

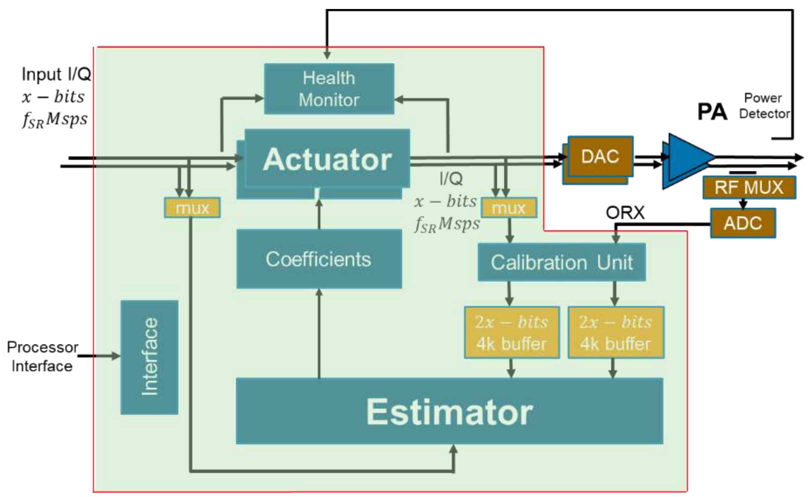

Figure 2: NanoSemi Linearizer™ core with two actuators with one estimator for 2x2 MIMO.

The NanoSemi Linearizer Core is NanoSemi's digital pre-distortion linearizer engine to correct for nonlinear distortions in the transmit path. It consists of an actuator to apply a pre-distorted digital signal, estimator to compute and update coefficients used by the actuator.

In this paper, we will use the Linearizer as an example to explain how NanoSemi is unique.

Many experts in the industry have pursued digital pre-distortion (DPD) in the hopes of implementing a transmitter with higher power efficiency in a wireless or wireline communication system. Since the power amplifier (PA) dominates nonlinear distortions of a transmitter, the focal point to improve an overall system power efficiency has been to utilize a highly power-efficient PA, sacrificing linearity. They then use some kind of DPD to bring the linearity back into spec. Many DPD experts in the industry are familiar with conventional DPD models based on Memory Polynomial (MP) and Generalized Memory Polynomial (GMP) basis functions.

MP

$$u_{dpd}[n] = \sum_{k=1}^{K} \sum_{m=0}^{M} c_{km,1}\, u[n-m]\, |u[n-m]|^{k-1} \qquad (1)$$

GMP

$$u_{dpd}[n] = \sum_{k=1}^{K}\sum_{m=0}^{M} c_{km,1}\, u[n-m]|u[n-m]|^{k-1} + \sum_{k=2}^{K}\sum_{m=0}^{M} c_{km,2} u[n-m]|u[n-m-q]|^{k-1} + \sum_{k=2}^{K}\sum_{m=0}^{M} c_{km,3} u[n-m]|u[n-m+q]|^{k-1} \quad (2)$$

As bandwidth of a signal increases, GMP with cross terms is better suited (and more widely used) than MP. As the PA becomes more nonlinear, many more higher-order dynamic terms are needed. For wider bandwidth, many more delay terms are also needed. However, such complicated DPD structure does not accurately represent the nonlinear behavior of a wide band PA and all the interactions within the transmitter. As a result, the DPD implementation based on GMP basis functions for a highly power efficient and wide band PA is not practical and instead, the PA must be backed off to operates far from Psat (i.e., Pout << Psat-PAPR (peak-to-average ratio)) at the expense of lower power efficiency.

In contrast, NanoSemi's linearizer, and the actuator in particular, is *not* based on GMP basis functions but is a transformation to a unique mathematical representation. It results in significantly smaller implementation size and power dissipation. It accurately identifies and corrects for nonlinear distortions close to noise floor.

Let us compare conventional DPD with NanoSemi's IP.

Conventional DPDs have to store a large set of coefficients in look-up tables. These coefficients were calculated and stored during factory calibration. An appropriate bank of coefficients is selected for different operating conditions, such as power level and temperature, during operation (run-time). As the bandwidth increases, the PA behavior deviates further and further from a predictable polynomial function, resulting in a DPD with an impractically large set of coefficients and a long factory calibration time.

In contrast, NanoSemi IP utilizes a real-time estimation. When a receiver is off-the-air (or by using a dedicated observation feedback receiver), it takes samples from the output of PA and stores 2000-4000 samples in a buffer. The estimator re-computes coefficients for the actuator in the background and updates them. The off-the-air duration is in µs. The estimation time (or convergence time) is ~ms – tens of ms. The estimator is implemented in a small number of logic gates and does not require a dedicated processor. This small, low-power estimator makes real-time update of coefficients possible. The coefficients are adapted for a different carrier configuration, a load change at antenna, temperature and power level and other conditions. Furthermore, an ability to utilize a receiver as needed for feedback and ADC (analog to digital converter) at same or lower sampling rate than DAC (digital to analog converter) reduces the overhead of a real-time adaptation while providing a robust linearized system with a smaller storage and also saving a factory calibration time.

Results

Below are two possible scenarios for a 64x64 MIMO radio: 1) NanoSemi's linearizer is used 2) conventional DPD is used. The example illustrates the impact on overall system power efficiency. Suppose the 64x64 MIMO radio is for a 5G platform, operating at 3.5GHz band with 200MHz instantaneous bandwidth. Each power amplifier outputs ~5W.

Scenario 1) If the PA is a GaN Doherty configuration, the power efficiency of 40% is achievable (when Pout=P_{sat}-PAPR). A resulting power dissipation of 64 power amplifiers with 40% power efficiency is 800W.

Scenario 2) a DPD implementation based on GMP basis functions is so large (or consuming significant power) that the PA is backed off far from P_{sat}, resulting in power efficiency of 25% (and using a larger PA to output same 5W). The resulting power dissipation of 64 PAs is 1280W.

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Assume the power dissipation of 64 DPDs is <1W and thus is not included in this calculation. The difference in power penalty of this 64x64 MIMO radio from PAs is 480W when the DPD implementation is based on conventional GMP.

Another example is compared earlier in Table 2. When the design of 5G mm-wave array or 802.11ad 60GHz array was considered, most system designers have dismissed DPDs as impractical because DPD for such large bandwidth (800MHz or 2GHz) require very high order terms and thus a very large and complicated implementation. As a result, the PA has power efficiency <5% and outputs 7dBm as an example. If the array must provide 22dBm of output power (ignoring the other losses), 32 elements are needed. With NanoSemi's linearizer, savings are significant in overall array size by 2x (32 vs 16 elements), thermal cost by 3x (3.2W vs. 1.07W including NanoSemi's linearizer power dissipation) and silicon die cost by $2.44.

In summary, NanoSemi's characterization process accurately models nonlinear dynamic system, NanoSemi's linearizer has an accurate representation of a very nonlinear but highly power-efficient PA and the entire transmit and receive chain. It has proven to exceed 5G and Wi-Fi (802.11ax and 802.11ad) performance spec with a very small implementation size and low power for a wide bandwidth. It is the only solution with a real-time adaptation for a power-sensitive mobile device.

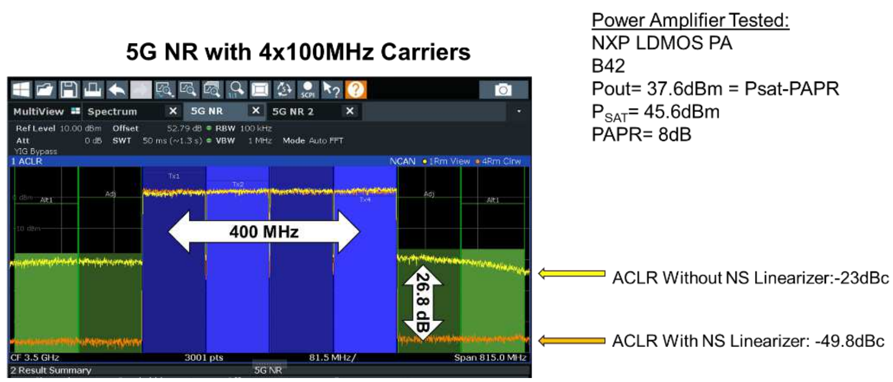

Figure 3: Output of PA with 5G NR waveform with and without NanoSemi Linearizer

Note About Envelope Tracking

Many of the LTE (and previous standards) SoCs for mobile devices have implemented an envelope tracking technique, which has an envelope amplifier that provides a dynamic drain voltage according to its envelope signal level. This results in a power-efficient system because PA is biased according to the envelope signal level. For a relatively low bandwidth, 40MHz, this technique addressed the improved power efficiency. For 5G mobile devices where bandwidth is at least 100MHz and higher, the envelope amplifier or envelope tracker does not turn on/ off the drain voltage of the PA fast and thus, its power efficiency is significantly lower (lower than Doherty PA). A remedy to recovering power efficiency is to push the switching speed of the envelope amplifier. However, it will result in many undesirable nonlinear distortions. With NanoSemi's linearizer with an envelope tracking actuator and estimator options, nonlinear distortions will be cleaned up effectively and efficiently.